Tracking the Rapid Pace of GIS-Related Capabilities and Their Accessibility

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Abstract

*With the rapid expansion of geographic information systems (GIS) technology and its integration into the wildlife biology field, it is becoming increasingly clear that having access to the full scope of its analytical tools will greatly improve our ability to study, understand, and manage wildlife populations. We use our long-term, white-tailed deer (*Odocoileus virginianus*) research project as a case study to highlight the significant advances in GIS that have been benefiting investigations of wildlife. From initiation of our research, we included early GIS capabilities and we attempted to take advantage of advances as they occurred. Herein, we document changes that occurred in "wildlife GIS" over the last 15 years and how we applied them in our work. We identify a list of sources of GIS tools and data that are currently available and discuss their potential value to wildlife researchers and managers.*
(WILDLIFE SOCIETY BULLETIN 34(5):1446–1454; 2006)

Key words

ArcView extensions, geographic information system, Global Positioning System, remote sensing.

Enhancing our understanding of relations of free-ranging animals with plants and habitat over varying spatial and temporal scales is essential to effective wildlife management. While our current knowledge of these areas may be credited to a wide array of tools and techniques historically employed in wildlife research and management, it is becoming increasingly clear that continued advancements in geographic information systems (GIS), compatible computer-related technologies (e.g., remote sensing, radiotelemetry, and Global Positioning System [GPS]) will be important to achieve the level of understanding required as management issues intensify (O'Neil et al. 2005). Particularly for large, mobile mammals, the integrated application of GIS and related technologies (e.g., GPS telemetry) may offer the greatest potential for scientists to accurately monitor and analyze locations and movements over time and to focus with greater resolution on habitat selection, vegetation changes and responses, and numerous other ecological relationships (Clark et al. 1993, O'Neil et al. 1995, Bettinger et al. 1997, 1999, Rempel and Rodgers 1997, Turner et al. 1997*a*,*b*, Boyce et al. 2003, Fortin et al. 2005).

In conducting our work over the last 15 years, we have been struck by the rapid pace of advancements and increasing accessibility of GIS tools (e.g., ArcView extensions, scripts) and programming languages (Arc Macro Language [AML], Avenue, Visual Basic [VB], Python). Together, these have streamlined the process from remotely sensed imagery to the development, maintenance, and updating of the vegetation–habitat and animal-location layers required for spatiotemporal analyses of animal movements, habitat use, and "special site" (e.g., fawning sites) characterizations. Although the emergence of new GIS capabilities was not always in time to benefit our research before completing specific phases of this process, the expanding variety and refinements of tools available have improved the breadth, quality, and efficiency of work that can be accomplished. Perhaps the greatest challenge has been staying informed of developments in this field, which are occurring at an increasingly rapid pace.

Although many published studies have relied on GIS tools and capabilities, there is little in the current wildlife literature that addresses technical issues and challenges and offers solutions. We believe this is unfortunate, as others likely would be assisted in more efficiently and effectively overcoming similar obstacles and avoiding potential pitfalls. We have attempted to stay current on practical GIS use during the past 15 years of our research. Our intention here, by way of a retrospective that in part uses our white-tailed deer (*Odocoileus virginianus*) research as a case study, is to highlight advances in GIS and the relative pace at which they are occurring. We hope this information will illuminate the direction and capacity of this technology as it progresses and is applied in future wildlife studies. Specifically, our objectives are to 1) describe our use of GIS and related challenges from initiation of our study, 15 years ago, to the present; 2) discuss advancements in GIS and related technologies in a similar time frame; and 3) highlight a variety of current specific GIS tools, sources of remotely sensed imagery and data and their availability, and potential in present and future wildlife research.

Early Applications of GIS-Related Technology in Wildlife Studies

Radiolocation telemetry systems (i.e., narrow band) were introduced to wildlife research in the late 1950s (LeMunyan et al. 1959, Cochran and Lord 1963). Since the 1960s very high frequency (VHF) radiocollars continue to be a

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universal tool for studying animal movements, home range, use of vegetation and habitat, survival, cause-specific mortality, and other aspects of animal ecology (Cochran 1980, MacDonald and Amlaner 1980, Mech 1983, White and Garrott 1990, Fuller et al. 2005).

In 1978 the Argos satellite collection system (<http://www.cls.fr/manuel/>), using satellite transmitters called platform transmitter terminals (PTTs), began locating animals fitted with satellite radiocollars around the world (Strikwerda et al. 1986). The PTTs transmit signals to polar-orbiting satellites, which relay the signals to processing centers in the United States and France. The data can then be downloaded via the Internet.

The GPS was developed by the United States Department of Defense (DOD) in 1973, providing 3-dimensional positioning worldwide for military applications (Navigation Signal Timing and Ranging Global Positioning System 1996). However, it was not until 1993 that refinements in GPS-receiver design permitted application of this technology to studies of wildlife. Rodgers and Anson (1994) fitted GPS collars to caribou (*Rangifer tarandus*) and evaluated their effectiveness under field conditions. Increasingly, GPS collars are being used to study movements, survival, and habitat use of elk (*Cervus elaphus*), moose (*Alces alces*), white-tailed deer, grizzly bears (*Ursus arctos*), and wolves (*Canis lupus*; Moen et al. 1996, Rodgers et al. 1997, Merrill et al. 1998, 2004, Parker et al. 2004; C. Kochanny, Advanced Telemetry Systems, unpublished data). Advantages of radiocollars incorporating GPS technology (vs. conventional VHF) include more frequent and consistently accurate (<31- to 100-m error), 24-hour, remote-location sampling, unrestricted by weather conditions (D'Eon et al. 2002; C. Kochanny, unpublished data). Consequently, the spatial and temporal resolution of data secured by GPS collars permit a more detailed and thorough examination of movements, habitat use, and animal–plant interactions (Rempel et al. 1995, Boyce et al. 2002, Fortin et al. 2005; C. Kochanny, unpublished data), despite the persistence of certain field application and analytical challenges (Moen et al. 1996, 1997, Frair et al. 2004). Additional details of GPS technology are provided by O'Neil et al. (2005).

Remote-sensing techniques (e.g., aerial photointerpretation) have been used in wildlife work since the mid-1900s (Leedy 1948, 1953). Since then, products generated (e.g., land-use and cover data generated from satellite imagery; digital orthophoto quads [DOQs]) have been common and invaluable to large-scale wildlife studies (Anderson et al. 1980, Koeln et al. 1994, O'Neil et al. 2005). Since 1972 the serial launching of 7 Landsat satellites (No. 7 in 1999), fitted with various scanners, has provided satellite imagery of the earth's resources and, with subsequent digital image processing, has been invaluable to wildlife habitat work (Work and Gilmer 1976, O'Neil et al. 2005). Digital orthophoto quads, with the properties of rectified air photographs with distortion removed, were made available to states in the mid-1990s as 7.5×7.5-minute (1:24,000) quadrangles and 3.5×3.5-minute (1:12,000) quarter-quadrangles (United States Geological Survey [USGS] 1996). Overlaying this coverage with map information, including contour lines, traditionally observed on USGS topographical (topo) maps is a relatively simple matter using GIS. Digital orthophoto quads are invaluable for fieldwork and habitat analyses.

Applications of GIS technology in wildlife research and management were introduced more recently, and technical refinements, rapidly expanding capabilities, accessibility, and their ease of use are increasing the frequency with which they are being employed (Koeln et al. 1994, O'Neil et al. 2005). Most of the early applications of GIS in wildlife work were conducted at a broad landscape scale and included habitat assessments using satellite-based imagery (Barnard et al. 1981, Cannon et al. 1982, Leckenby et al. 1985), animal inventory (Strong et al. 1991), and creation of ecological land-classification systems (Davis and Dozier 1990). In the mid-1990s, biologists began using GIS in smaller-scale projects, such as habitat studies of nesting sandhill cranes (*Grus canadensis*; Baker et al. 1995), muskoxen (*Ovibos moschatus*; Danks and Klein 2002), and Florida scrub jays (*Aphelocoma coerulescens*; Breininger et al. 1991), as well as for regional moose surveys (Lynch and Shumaker 1995; M. S. Lenarz, Minnesota Department of Natural Resources, unpublished report).

Evolving GIS-Related Capabilities and Accessibility: A Case Study

In winter 1990–1991, we began a long-term field experiment for the Minnesota Department of Natural Resources (MNDNR) to study the effects of winter severity and diminishing conifer cover on various aspects of white-tailed deer ecology, including their use of vegetation and habitat (DelGiudice 1994, DelGiudice and Riggs 1996, DelGiudice et al. 2002, 2006). Our study design included 3 phases: 5-year pretreatment, 4-year treatment (i.e., harvesting of conifer cover), $\geq$6-year posttreatment, and it required an analysis of vegetative composition and deer habitat on 2 control and 2 treatment sites, which ranged from 10–22 km^2.

Our procedure for developing vegetative databases and GIS layers for the 4 sites to serve as the basis for subsequent spatial and temporal analyses of deer use of habitat was standard for the time (Table 1). We shot new color infrared aerial photos in stereo for all 4 sites. Using a mirror stereoscope (Model MS-27; Sokkisha Co. Ltd., Tokyo, Japan), we conducted a detailed air photointerpretation of each site according to a vegetation classification system developed for the study. Geo-referencing (i.e., establishment of a positional reference between a photo and real world coordinates) of photos required that a minimum of 4 GPS registration points be acquired per overlapping "effective area" of the stereo photo pair in the field. We used a portable GPS (Geoexplorer II; Trimble Navigation Ltd., Sunnyvale, California) for this task; handheld units were not yet being marketed. Collection of registration points was a time-consuming process because a predominant

Table 1. Steps in developing and using a vegetative database for spatiotemporal analyses of winter habitat for white-tailed deer in a geographic information system, 2 treatment and 2 control study sites, north-central Minnesota, 1991–2005.

Prepare source imagery	Develop vegetation layer	Analyze and report
Shoot color infrared air photos	Interpret imagery	Spatial and temporal analyses
Collect GPS[a] registration points	Digitize aerial photointerpretation	Develop final maps
Scan and rectify imagery	Rubber-sheeting	Publish results
	Clean and build topology	
	Populate attribute tables	
	Develop preliminary maps	

[a] GPS = Global Positioning System.

cover type on our winter-range study sites was lowland swamp with standing water prevalent during the non-winter season. At the time field accuracy of most handheld GPS receivers was ±100 m due to "selective availability" (SA; i.e., satellite timing signals intentionally degraded by the DOD). Global Positioning System satellites broadcast extremely accurate and precise time signals, which GPS receivers use to triangulate their location, elevation, and velocity. However, when DOD had SA "turned on," the timing signal on the civilian channel was degraded to produce location errors of ≤100 m. Consequently, field-collected GPS points had to be "postprocessed" to attain the accuracy necessary for geo-referencing. This time-consuming process compared field locations stored in a rover file to a file of locations collected at a base station with a known accurate location. Postprocessing reduced our location error from 100 to 3 m. To ensure that at least 4 points per effective area were usable, we collected at least 8 GPS points per effective area of a stereo photo pair for a total of 112 points.

"Heads-up" or on-screen digitizing did not exist at that time, so we accomplished table-digitizing of interpreted forest cover polygons and other landscape features (e.g., streams, lakes, roads) using a large-format 1 × 1.3-m digitizing table (Model HDG-3648S; Hitachi Seiko Ltd., Tokyo, Japan) connected to a desktop personal computer (PC; PS2 Mod 50; IBM, Armonk, New York) running EPPL7 (Land Information Management Center, Minnesota Department of Administration, St. Paul, Minnesota). Once each photo's interpretation was digitized in EPPL7, we transferred the line file (i.e., lines with coordinates delineating the interpretation) to a SUN Unix Workstation (Sun Microsystems, Santa Clara, California).

Table 2. Chronology of geographic information system (GIS) software and data development.

Year	Software	Data[a]
1977	Eppl 1	
1978	Erdas Imagine	
1982	Arc/Info 1 and Grass	
1986	Personal computer Arc/Info	
1987		NAPP
1990		GAP
1991		DOQs
1992	ArcView 1	
1994	ArcView 2	
1995		DRG
1996	ArcView 3	
	ArcView Spatial Analyst extension	
1998	ArcView Image Analyst extension	
2000		National Land Cover
2001	ArcGIS 8.X	
2003		FSA leaf-on photos
2004	ArcGIS 9.0	
2005	ArcGIS 9.1	

[a] NAPP = National Aerial Photograph Program; GAP = Gap Analysis Program; DOQ = digital orthophoto quad; DRG = digital raster graphics; FSA = Farm Service Agency.

Arc/Info (Environmental Systems Research Institute [ESRI], Inc., Redland, California) was the primary GIS software available at that time, and commonly it was run on large workstations, not on desktop PCs. Desktop GIS programs had not yet been developed, and the Internet, as we know it today, did not exist. We did our original GIS work over an Ethernet network connection from a desktop PC to a Sun Workstation. Because the network connection failed frequently, we saved the work frequently to prevent it from being lost. Using Arc/Info (Table 2), digitized juxtaposed lines of adjacent stereo photo pairs were fit as accurately as possible (i.e., rubber-sheeted), after which we edited the Arc/Info coverage to clean up areas where adjacent polygons did not meet accurately (i.e., slivers and dangles). This was very time-consuming. After we cleaned the coverage and built topology (i.e., spatial relationships between connecting or adjacent features), we developed the attribute table for each polygon with descriptive data from the air photointerpretation, including dominant tree species and their height and canopy closure classes (e.g., <40%, 40–69%, and ≥70%; DelGiudice 1994).

In 1990 our base map, and that used by most biologists, was the standard USGS 7.5-minute quadrangle topo map (<http://topomaps.usgs.gov/>). This map was acceptable for rudimentary navigational use but not for plotting animal locations accurately or for other more detailed work. We located radiocollared female deer 1–3 times per week from a fixed-wing aircraft during late autumn to early spring. Plotting aerial telemetry locations on a topo map in a small fixed-wing aircraft was cumbersome. Finding the correct map and accurately plotting the location was particularly difficult for study sites covered by several different topos or during periods of seasonal migration when deer were between winter study sites and their spring–summer–autumn ranges (3–32 km apart; DelGiudice 1998). During the first 6 years of our study, most of the USGS maps that covered our sites and surrounding areas out to the spring–

summer–autumn ranges, were produced in 1953, 1970, and 1971, and thus were largely outdated and sometimes lacked usable landmarks. Updates of a number of these maps were not available until 1996.

In 1998 we produced our own base maps from a composite of current rectified air photos to facilitate plotting of more accurate aerial telemetry locations of our collared deer. These current base maps permitted easy identification of individual stands of vegetation, roads, trails, and other landmarks on our sites, which also facilitated more efficient ground navigation for other aspects of our fieldwork.

Advancements in GIS Technology and Data Availability

During the 1990s the data-processing and storage capacities of desktop PCs rapidly approached that of large, expensive workstations. This allowed biologists access to computers capable of more advanced GIS work, which has been supported by a proliferation of GIS software (Table 2). With the introduction of ArcView in 1992, which was far more user friendly than Arc/Info, desktop GIS has become commonplace, and new, valuable sources of data have become available (Table 2). For example, the USGS started work on a nationwide set of DOQs (<http://online.wr.usgs.gov/ngpo/doq>) of 1-m resolution using the first cycle of black-and-white aerial photos from the National Aerial Photography Program (<http://edc.usgs.gov/products/aerial/napp.html>). These photos cover the United States and have been flown on a 5- to 7-year cycle since 1987. Photos used to produce the first DOQs that included our study sites were flown in 1991 and 1992. In 1995 USGS released the first set of digital raster graphics (DRGs; <http://topomaps.usgs.gov/drg>). The DRGs are georectified, high-quality, scanned reproductions of USGS 7.5 × 7.5-minute (1:24,000) quadrangles. Both of these provide large-scale rectified base maps for much of the continental United States and are available from the USGS Earth Science Information Center (<http://geography.usgs.gov/esic/esic_index.html>).

By this point the development of GIS analytical tools and techniques was accelerating (Table 3) with a concomitant increase in the type and frequency of GIS applications. In 1994 and 1996, ArcView v.2.0 and v.3.0 (ESRI), respectively, were released (Table 2). The introduction of ArcView brought some of the power of workstation-based Arc/Info to the desktop. Also, in 1996 the Spatial Analyst extension (ESRI) for ArcView was released. This extension equips biologists with a large set of advanced spatial analysis tools for both vector and raster data. The Image Analyst extension followed in 1998, providing advanced image-analysis tools and, specifically, it allowed a wide range of image data types to be used in image categorization and registration, feature extraction, and simple change detection. Other now-common desktop GIS programs and data viewers include Geomedia Viewer (<http://intergraph.com/gviewer>; Intergraph, Madison, Alabama), Geoexpress (<http://lizardtech.com/products/geo>; Lizard Tech, Seattle, Washington), Geomatica Freeview (<http://pcigeomatics.com/products/freeview.html>; PCI Geomatics, Richmond Hill, Ontario, Canada), ArcExplorer (<http://esri.com/software/arcexplorer>; ESRI), and Erdas Imagine (<http://gi.leica-geosystems.com/Products/Imagine>; Leica Geosystems GIS and Mapping LLC, Atlanta, Georgia).

On 1 May 2000 the DOD turned off SA, which greatly increased the accuracy of GPS-derived locations and made postprocessing of GPS data unnecessary in most instances. This was a milestone, and GPS-associated error is now ≤10 m for most handheld GPS units.

In 2001 ESRI released ArcGIS Version 8 (<http://esri.com/software/arcgis/>). With this release came a fundamental change in the look, feel, and capabilities associated with ArcView and Arc/Info. ArcGIS operates on high-end desktop computers and provides 3 different license levels of GIS functionality: 1) ArcView provides extensive mapping, analysis, editing, and geoprocessing tools; 2) ArcEditor affords advanced editing functions not available in ArcView; and 3) ArcInfo is the full-function GIS desktop software that extends the ArcView and ArcEditor capabilities and provides the most advanced geoprocessing. ArcReader (a free product) can be used to simply view and print maps and data generated using other ESRI desktop software.

In 2003 the United States Department of Agriculture's Farm Service Agency (FSA; <www.apfo.usda.gov/>) collaborated with a variety of local partners (e.g., MNDNR, Land Management Information Center) on a project that employed rectified summer "leaf-on" photos to check compliance within certain agricultural programs. This new statewide photo coverage also provided an excellent base map image, and, as part of a cost-sharing partnership, it is being updated annually with 1-m and 2-m accuracy every 5 years and in the intervening years, respectively. The FSA is in the process of forming similar partnerships in other states.

Minnesota Department of Natural Resources' Extensions and Tools for ArcView 3.X

Since 1991 the MNDNR Management Information Systems' GIS staff has been developing and expanding a large suite of easily accessible ArcView extensions to assist its employees with land-use planning and decision-making (Table 3). These extensions are available for free download from the MNDNR website (<www.dnr.state.mn.us/mis/gis/tools/Arcview/extensions.html>). The following extensions have been particularly useful for wildlife research and management. Brief descriptions of some of the most commonly used extensions follow.

ArcView -> EPPL7 Extension can contribute to the efficiency of developing a spatial database in a number of ways. It allows on-screen image rectification of raster images and involves using a scanned photo on one side of the computer screen and a previously rectified photo (e.g., DOQ) on the other. Using this extension to take advantage of the map coordinates from the DOQ to rectify project

Table 3. Some ArcView extensions available for download from the Minnesota Department of Natural Resources website (<dnr.state.mn.us/mis/gis/tools/arcview/extensions.html>), with a brief description of their function.[a]

Extension	Description
ArcView -> Eppl7 Extension	
Rectify image	Rectifies an unrectified raster image file
Clip image	Clips a raster image file to the boundary of a selected polygon
Clip image on graphic	Clips an image file to the boundary of a selected polygon graphic
ArcView Tools Extension	
Clip	Clips vector themes to shape of selected polygons
Buffer	Creates a buffer polygon around selected features of a theme
Intersect	Intersects 2 themes
Merge	Merges 2 or more themes together
Erase	Erase from one theme the area that intersects features from another theme
Union	Union 2 themes
Subset a legend	Subset a legend to only those classes that exist in the current data
Calculate area, perimeter, length	Calculate feature geometry for a theme
Shift theme	Shift coordinates for a theme
Ungroup features	Ungroup features in a theme
Polygon to poly lines	Convert a polygon file to a line file
Stream Mode Digitizing Extension	
Smooth lines	Eliminates vertices within a specified tolerance
Distance tolerance	Specify distances between vertices when digitizing lines
Weed lines	Performs on-the-fly vertex weeding at the specified distance tolerance
Auto pan	Auto pans when digitizing within 5% of the window edge
Split	Splits a line or polygon feature
Append	Creates a new polygon feature next to an existing polygon
Polygons	Digitizes polygons in stream mode
Lines	Digitizes lines in stream mode
Interactive distance tolerance	Specify distance tolerance interactively
Garmin GPS Extension	
Download waypoints, tracks, routes	Download from GPS and save as ArcView shapefile or routes graphic
Upload waypoints, tracks, routes	Upload shapefile from ArcView into GPS
Real-time tracking	Collect real-time locations and store as graphic or ArcView shapefile
Waypoint to point	Convert GPS waypoint to an ArcView point shapefile or graphic
Track to point, line, polygon	Convert a GPS track log to an ArcView shapefile or graphic
Point to waypoint	Convert ArcView point shapefile or graphic to a GPS waypoint
Line polygon to track	Convert line or polygon to a GPS track
Point to line/polygon	Convert GPS waypoints to lines or polygons
Add documentation	Add documentation to themes including GPS model, date, agency
Calculate shape attributes	Calculates area, perimeter, length attributes for features
Calculate CEP	Calculates CEP rings for error estimation
Image hot linking	Create hotlinks between images and GPS data
USB connectivity	Speeds up downloads with new USB connectivity option

[a] GPS = Global Positioning System; CEP = circular error of probability; USB = universal serial bus.

photos saves significant time and cost associated with field collection of registration points. The EPPL7 also can be used to clip raster images to whatever size required by specific projects and to merge photos before digitizing. This eliminates the need for rubber-sheeting and minimizes the production of most slivers and dangles, which contributes to process efficiency and spatial accuracy.

ArcView Tools Extension was developed for modifying ArcView themes (e.g., land use, forest cover, roadways, hydrology, study area boundaries). These tools allow users to easily clip, buffer, intersect, merge, erase, union, and shift themes. It also contains a feature that recalculates the feature geometry (i.e., area, perimeter, length) after modifying corresponding shapefiles.

Stream Mode Digitizing Extension supplies a set of tools for heads-up digitizing of lines and polygons. Heads-up digitizing involves using a mouse to trace polygons or lines displayed on the computer screen. Advantages of this process include 1) efficiency through automation, (i.e., the user does not have to click each location where a vertex is wanted; rather, vertices are added automatically as the user traces with the mouse), 2) efficiency facilitated by auto-panning and advanced zoom features, 3) ability to append to existing polygons and to split polygons and lines, 4) setting of vertex spacing and line-smoothing parameters prior to digitizing, and 5) eliminating potential ergonomic stress from bending over a large digitizing table for hours at a time.

Garmin GPS Extension allows downloading and uploading of waypoints, tracks, and routes collected in the field between GPS units and various GIS software. This allows field surveys to be set up in a GIS and then uploaded to a GPS unit. This extension also can be used for real-time tracking and to convert GPS-collected features (e.g., point locations and tracks) into ArcView shapefiles. The DNR Garmin also is available in a stand-alone VB version for use with ArcGIS Version 8.X and ArcGIS Version 9.X. This extension is being used worldwide. It is continually being updated, so users should check frequently for enhancements.

DNR Random Sample Generator provides a group of diverse sampling schemes for biologists to use, including random, systematic, and triangular point, and hexagonal polygon. It also includes transect, random segment, and systematic segment generators, which provide biologists with many options during study design and implementation.

DNR Wildlife Survey Extension was designed for biologists who conduct aerial surveys and would like to display real-time tracking of the flight while displaying background themes such as air photos and survey transect lines. The extension will also save a copy of the flight path and any animal observation data to a set of shapefiles. This extension works in conjunction with a GPS receiver and the DNR Garmin program running in the background. The extension can incorporate a tablet-style PC that uses a digitizing pen for input. All data entry is menu-driven and can be input quickly with the digitizing pen. This simplifies data entry and allows the observer to spend more time observing. The source code is written in Avenue and VB and can be downloaded to customize the survey to better fit individual needs.

Extensions and Software Available from Other Sources

Another source of ArcView extensions is the ESRI website (<http://arcscripts.esri.com>). Their website has downloadable tools and extensions for all of the ESRI products. Searches can be made by type of software and by programming language. Their search engine allows users to find various tools such as extensions, AMLs, and Avenue scripts, most of which are written for specific problems and, hence, provide specific solutions. Wildlife-specific analytical extensions, including tools for spatial and theme conversions, analysis of animal movements and home range, also have been made available by the Oregon Department of Forestry (<www.odf.state.or.us/divisions/management/state_forests/XTools.asp>), the USGS Alaska Science Center (<www.absc.usgs.gov/glba/gistools>), Jenness Enterprises (<http://jennessent.com/arcview/Arcview_extensions.htm>), and by A. Rodgers and A. Carr (<http://blue.lakeheadu.ca/hre>). The Wildlife Society's (TWS) GIS, Remote Sensing, and Telemetry Working Group (<http://fwie.fw.vt.edu/tws-gis/>) offers to TWS members an excellent list of sources for GIS, GPS, and telemetry information. A useful source of state-by-state GIS data websites is available at <http://libraries.mit.edu/gis/data/datalinks/statedataweb.html>.

Non–ESRI-based GIS software also is available and can be downloaded from <www.geocomm.com>. This site provides a free evaluation copy (i.e., limited functionality). Most of these products allow various types of data to be used, such as ArcView shapefiles (.shp), Arc/Info interchange files (.E00), Digital Line Graph (DLG), Digital Elevation Model, Multi-Resolution Seamless Image, Tagged Image File Format, and Joint Photographic Experts Group. Most are relatively easy to use and are designed for beginning GIS users. Taking advantage of this free software is an excellent way to get started in applying GIS technology at minimal cost. Available free and fee-pay data downloads include Land Use/Land Covers, DOQs, DLGs, DRGs, National Wetlands Inventory, and Tiger Census Line files (depict streets, roadways).

Another tool that has become popular is the shareware program GPS Mapedit (<http://geopainting.com/en>). This program allows the user to create a GIS vector map (e.g., points, lines, polygons) and upload it onto a Garmin Map Series GPS receiver to use as a background map. Data from the attribute table can also be used to label items on the map that is displayed on the GPS. This can be very useful for many types of fieldwork (e.g., ground-truthing habitat polygons). It does not accommodate scanned images or air photos. Currently, it is not very user friendly; however, as more people become aware of its potential value, this should improve with product updates and enhancements.

Land cover data also can be obtained from the Gap Analysis Program (GAP; <www.gap.uidaho.edu>), a nationwide program coordinated in individual states by the Biological Resources Division of the USGS. Efforts to create a GAP in all 50 states are ongoing. Gap Analysis Program data include land cover, species-predicted distribution, and stewardship layers. The land cover layer is developed using Landsat Thematic Mapper imagery and can be used for habitat analyses of areas at the landscape scale. The National Land Cover Database, a nationwide standardized land cover layer, is available from the Multi-Resolution Land Characteristics Consortium (<http://www.mrlc.gov/index.asp>).

National Wetlands Inventory data are available for large portions of the country (<http://nwi.fws.gov/index.html>). These data, from the United States Fish and Wildlife Service, consist of wetlands delineated by type of vegetation and water saturation level. Currently about 90% of the lower 48 states and 50% of Alaska have been inventoried.

Conclusions

Project GIS data development, be it new data or modifying data from other sources, often is its most significant cost in both time and money. Using some of the aforementioned tools, the cost can be minimized and the biologists can proceed to GIS-assisted data analysis. Finding extensions, scripts, or data for specific applications can still be problematic, with users now migrating from ArcView to ArcGIS. The problem will be exacerbated by the lack of tools written specifically for use in ArcGIS, as Arcview 3.X extensions are not forward-compatible with ArcGIS. As the number of ArcGIS users increases, this problem should be alleviated.

Biologists and GIS specialists are continually responding with new extensions and scripts to specific problems within their projects, but unfortunately many of these solutions are not made available to other professionals via publication or the Internet. Large landscape-level data sets of various qualities are available from different sources but sometimes are difficult to access. Network data transfer speed, especially dial-up, continues to be a challenge when involving statewide extents of data from remote servers. But as GIS network technologies improve, it is becoming easier to retrieve and use high-quality GIS data. With the advent of the Web Mapping Service, it has become feasible to deliver large amounts of raster data on the Internet at very fast speeds. The data are stored on a central server, and the server does all of the work of selecting the requested data and resampling it to a smaller size, then sends the requested image back. Web Mapping Service only works on-line and requires a high-speed connection. Dial-up is too slow. Improved and more sophisticated tools are becoming available to all users at little or no cost. With the rapid growth of the Internet, the distribution of data and tools is being facilitated, making it easier for biologists to use GIS on their projects for spatial and temporal data analyses.

Wildlife biologists have had the ability to track and map free-ranging animal locations and movements, and their own, for decades. Similarly, they have had the ability to obtain remotely sensed imagery of the landscape and vegetative cover associated with those locations and movements. However, the persistent problem has been the relative crudeness, inaccuracy, and imprecision of these data. Certainly, the quality of the data may have been adequate to fulfill the objectives of some studies. But whether biologists actually recognized it, or appreciated the implications relative to the quality of their work, these technical limitations sorely limited data interpretations and conclusions drawn from many of the studies being done, and consequently has had the same effect on our understanding of various aspects of animal ecology. As GIS and compatible, computer-related technologies continue to evolve, allowing collection of data more truly representative of animals, their environment, and the relations between them, we think biologists will increasingly appreciate the limitations of our understanding (and sometimes misunderstanding) in the past and the enhancements to our evolving, expanding knowledge. These technologies are, in large part, about facilitating the collection of higher-quality data. How biologists subsequently analyze, present, interpret, and synthesize information from those data, and how it is applied by wildlife professionals to real-world management situations, is perhaps more critical and still should be approached with some caution or constraint.

Acknowledgments

The Forest Wildlife and Populations Research Group, MNDNR, supported our study, with additional funding from Reinvest in Minnesota, the Minnesota Deer Hunters Association, and the Special Projects Foundation of the Minneapolis Big Game Club. We gratefully acknowledge T. Loesch, C. Pouliot, and C. R. Perreault, application programmers for the GIS Section of the MNDNR, for writing the ArcView extensions, and R. G. Wright, MNDNR Wildlife GIS-specialist, for his technical support. C. R. Perreault, M. A. Larson, R. G. Wright, and P. R. Krausman provided constructive reviews of an early draft of this article.

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